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Evaluation of Titanium-5Al-5Mo-5V-3Cr (Ti-5553) Alloy Against Fragment and Armor-Piercing Projectiles

by Shane D. Bartus

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14. ABSTRACT

Ballistic tests were carried out on the relatively new titanium alloy Ti-5Al-5V-5Mo-3Cr (Ti-5553), which was subjected to two heat treatment conditions. The two heat treatments provided high-strength plates which were solution treated and aged (STA) and high toughness plates that were beta-annealed, slow cooled and aged (BASCA). The ~13.9-mm-thick plates were evaluated for V_{50} using 0.50-cal. FSP and 0.30-cal. AP M2 projectiles. The results were benchmarked against MIL-DTL-46077F and MIL-A-46077 D for weldable titanium alloy armor plate (Ti-6Al-4V). The BASCA plates exceeded the requirement for the 0.30-cal. AP M2 by 3.2% but fell short of the Ti-6Al-4V performance against the 0.50-cal. FSP projectiles by 11.3%. The STA plates exceeded the Ti-6Al-4V mil-spec requirement by 8.7% and 11.7% for the 0.30-cal. AP M2 and 0.50-cal. FSP projectiles, respectively.

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1. Introduction

Historically, the primary user of titanium alloys has been the aerospace industry. However, the drive to reduce military ground vehicle weight, coupled with issues related to the high cost and multiple impact requirements associated with composite/ceramic solutions, has made titanium alloys an attractive alternative for lightweight armor applications. Ti-6Al-4V is the typical alloy choice for armor applications and its ballistic performance is detailed in MIL-DTL-46077F (1998) and MIL-A-46077D (1978).

Burkins et al. evaluated the ballistic performance of Ti-6Al-4V with respect to annealing temperature (1997) and thermo-mechanical processing (2000). The V_{50} limit velocity was relatively insensitive to the annealing temperature below the beta transus temperature; however, the limit velocity decreased significantly above the beta transus temperature (Burkins et al., 1997). The resulting microstructure from the beta anneal changed the failure mode from that of bulging, delamination, shearing, and spalling to a low-energy failure mode of adiabatic-shear plugging (Burkins et al., 1997). Burkins et al. (2000) noted similar results for ELI Ti-6Al-4V plates annealed or rolled above the beta transus temperature.

The understanding of ballistic performance for Ti-6Al-4V under various processing conditions is relatively mature; however, literature on new titanium alloys is limited. Ballistic characterization of alternate alloy systems would provide armor designers with a means to reduce weight or increase protection if the said alloys performed better. One of the relatively new alloys is Ti-5Al-5V-5Mo-3Cr (Ti-5553). This near-beta alloy was introduced by Titanium Metals Corporation (Zeng, 2006) and the beta-annealed, slow cooled, and aged (BASCA) heat treatment is currently patent pending by Boeing (Boeing Material Specification, 2006). This alloy has several manufacturing advantages, such as castability (allowing production of near-net shapes) and weldability so that practical structures can be fabricated. Ti-5553 has a reported tensile strength up to 1309 MPa with more than 10% elongation (Zeng, 2006) compared with the 827 MPa minimum tensile strength specified for class 1 ELI Ti-6Al-4V with similar elongation (MIL-DTL-46077F, 1998). In addition, Ti-5553 exhibits excellent hardenability (up to 6 in/15.24 cm thick sections) (Veeck et al., 2004), which is an issue for thick sections (>1 in/2.54 cm) of Ti-6Al-4V (Donachie, 2000).

However, mechanical properties often do not correlate to ballistic performance (Nesterenko et al., 2003). Therefore, ballistic protection offered by titanium alloys cannot be inferred from tensile strength, hardness, elongation, reduction in area, or charpy impact. For these same reasons, macro-mechanical numeric models, which are based on material properties, tend to have difficulty matching experimental results without being calibrated to experimental data. Thus, evaluation of ballistic response must be determined experimentally with a range of projectiles which encompass what a fielded component is likely to see in service.

2. Background

Titanium undergoes an allotropic transformation above the beta transus. Below the beta transus temperature (882 °C for pure titanium), it exists in the hexagonal-close-packed (HCP) crystal structure which is known as the alpha (α) phase. The alpha phase is not stable above the beta transus temperature and the crystal structure changes to body-centered-cubic (BCC); the beta (β) phase, which is stable to melting point (Donachie, 2000). Commercially pure titanium has poor mechanical properties so it is often alloyed with additional elements to provide solid-solution-strengthening.

Alloying can drastically affect the allotropic transformation temperature. Additions of tin and zirconium provide solid-solution-strengthening without changing the beta transus temperature. Manganese, chromium and iron produce a eutectoid reaction, reducing the alpha-beta transition temperature and producing a two-phase microstructure at room temperature. Other alloying elements are referred to as alpha or beta stabilizers. Alpha stabilizers, aluminum, oxygen, hydrogen, etc., increase the temperature at which α transforms to β. Vanadium, tantalum, molybdenum, and niobium lower the transition temperature and can result in mestastable beta (or near-beta) structure at room temperature (Askeland, 1994).

Ti-5553 is a near-beta alloy because the large additions of V and Mo retain a high degree of beta structure at room temperature. Strengthening is obtained by the addition of solid-solution-strengthening elements and by aging the metastable beta structure to precipitate alpha. The alpha phase forms as finely dispersed particles within the retained beta (Donachie, 2000). There are several disadvantages of metastable beta alloys in contrast to alpha-beta alloys (e.g., Ti-6Al-4V), such as higher density and lower ductility (aged condition). In the Ti-5553 system, the BASCA heat treatment was developed to impart higher toughness while still maintaining a relatively high degree of strength. The STA heat treatment is employed to exploit strength. Beta annealing is carried out above the beta transus temperature where solution treating is done below the beta transus temperature, which is ~840 °C for the Ti-5553 system.

3. Materials

The chemical composition allowances for Ti-5553, outlined in the Boeing Material Specification, are shown in table 1. The four plates used in the present study were forged and rolled by Verkhnaya Salda Metallurgical Production Association (VSMPO), Sverdlovsk Region, Russia and were heat treated by Boeing, Berkeley, MO. Two 30.5-cm × 30.5-cm × ~13.90-mm-thick plates were subjected to solution treated and aged (STA) and two plates of the same size,

from the same heat,were subjected to BASCA. The heat treatments were carried out in accordance with the Boeing Material Specification (2006). The processing details are highlighted briefly.

A qualitative graphical representation of the STA and BASCA heat treatments is shown in figure 1. For the plates treated to BASCA, the beta anneal was held at 900 ºC (11.1 ºC/min ramp) for 90 min and then slow cooled 2.0 ºC/min to ~607 ºC. The plates were subsequently aged for 8 h and then furnace cooled. The solution treatment for the STA plates was performed at 827 ºC (11.1 ºC/min ramp), below the beta transus temperature, and held for 2 h before air cooling. Aging took place at 593 ºC (11.1 ºC/min ramp) for 8 h, then air cooled.

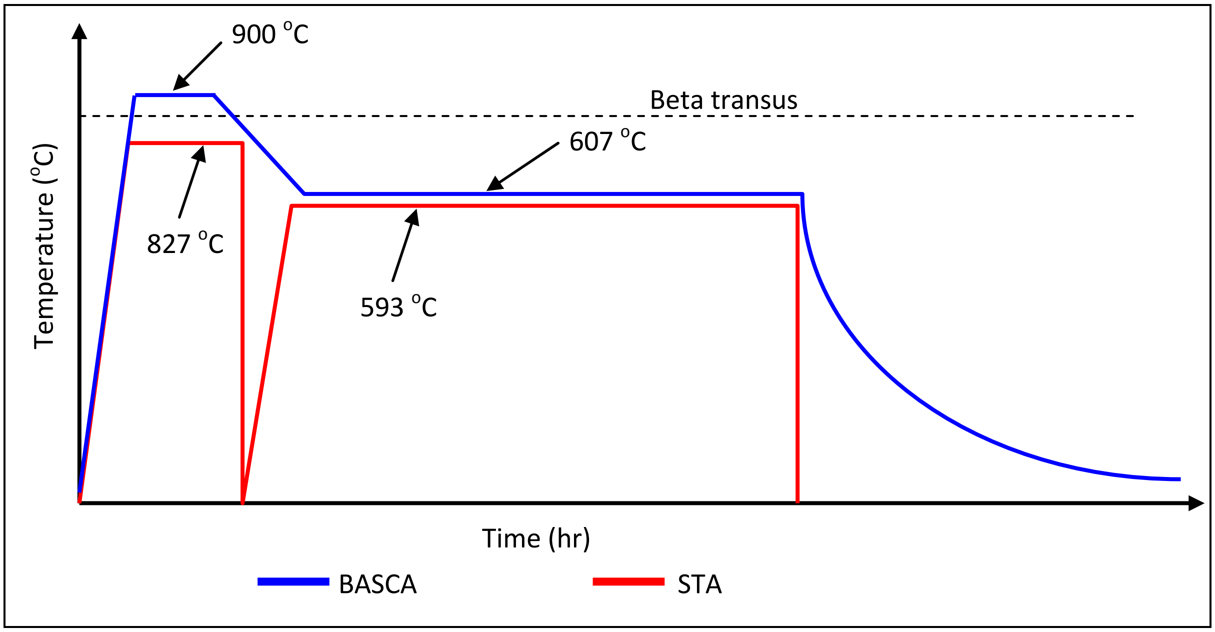

Figure 1. Processing schedules for the Ti-5553 plates subjected to the STA and BASCA heat treatment schedules (not shown to scale).

4. Test Projectiles

The 0.30-cal. (7.62-mm) armor-piercing (AP) M2 and 0.50-cal. (12.7-mm) fragment-simulating projectile (FSP) were selected for the study because they are listed as appropriate test projectiles in MIL-DTL-46077F and MIL-A-46077D, respectively, for the 13.9-mm plate thickness. The projectile details are shown in figure 2, and the required V_{50} test velocities for 0.30-cal. AP M2 and 0.50-cal. FSP projectiles are plotted as a function of ELI Ti-6Al-4V thickness in figure 3. The FSP represents high-velocity primary fragments from ordinance and is described in MIL-P-46593A (1964).

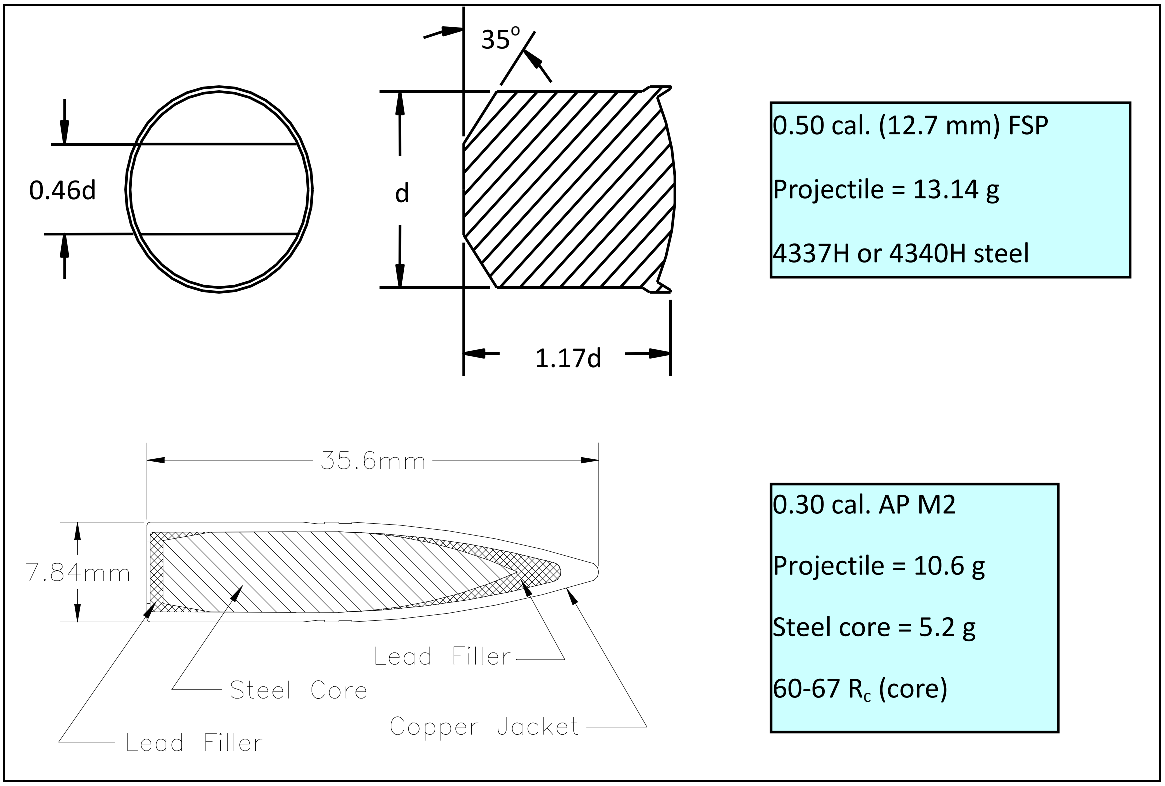

Figure 2. Details for the 0.50-cal. (13.9-mm) FSP and 0.30-cal. AP M2 projectile used in the study.

It is important to evaluate plate performance against both projectiles since it is possible for the penetration mechanisms to be different. In addition, previous work from Burkins et al. (2000) also indicated that FSPs where better at showing differences in plate performance due to microstructure changes than armor piercing penetrators.

5. Test Method

The V_{50} for the Ti-5553 plates with dimensions 30.48 × 30.48 cm^2 (~13.9-mm-thick) was determined against the 0.30-cal. AP M2 (MIL-DTL-46077F) and 0.50-cal. FSP (MIL-A-46077D), in the both STA and BASCA heat treatments (four targets total). Projectile velocities were measured using Oehler Model 57 infrared screens and Oehler Model 35 chronograph. The screens were placed normal to the barrel, spaced 61 cm apart. A proof channel was placed in between (30.5 cm away) as a check for erroneous measurements. The projectile velocity measured by the chronograph was checked against an orthogonal flash x-ray system, described in Burkins et al. (2000). A correction of 0.994 * (Measured Velocity) was applied to all chronograph measurements. Pitch and yaw were also initially measured and both were found to be less than 2º.

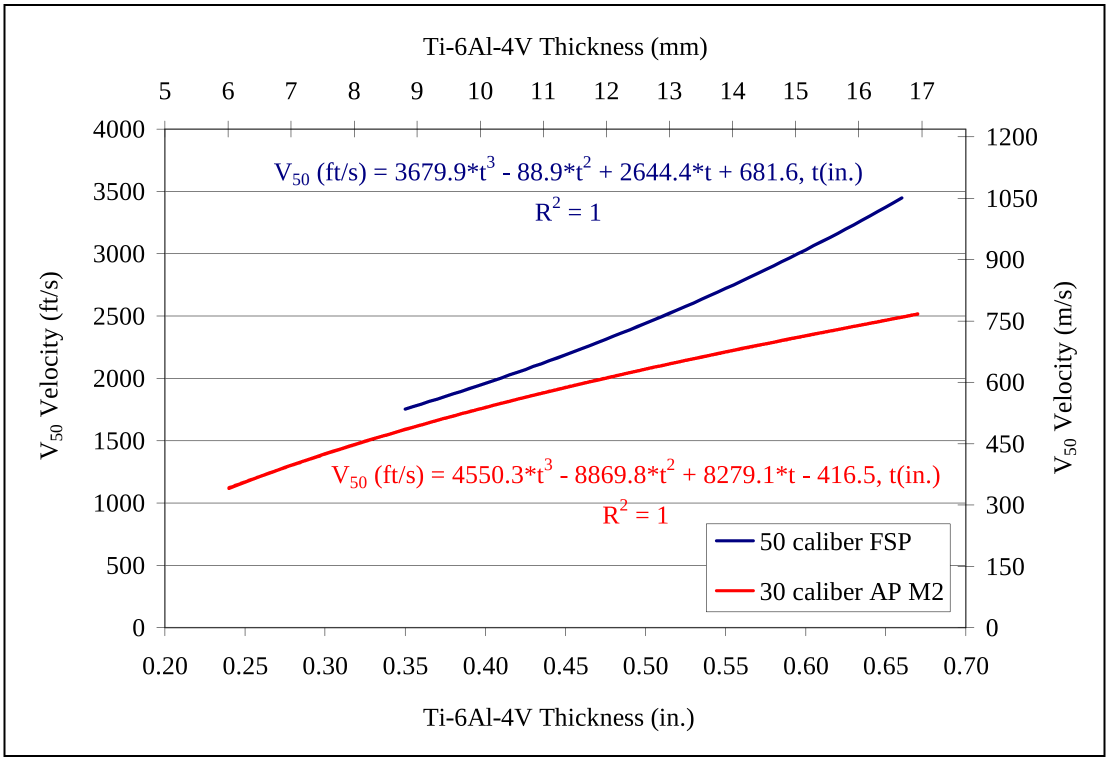

Figure 3. V_{50} minimum velocity requirements for a given thickness of Ti-6Al-4V armor plate against 0.30-cal. AP M2 (MIL-DTL-46077F) and 0.50-cal. FSP (MIL-A-46077D) projectiles.

All impacts were normal to the target which was placed 4.67 m from the barrel. The V_{50} was evaluated in an "up-down" manner in which the amount of propellant used was adjusted until a complete penetration (CP) occurred. The amount of propellant was then decreased until a partial penetration (PP) occurred and so forth. PPs and CPs were determined by placing a 0.508-mm-thick 2024-T3 aluminum witness plate 15.24 cm behind the target. If the projectile or ejected target material perforated the witness plate such that light could be seen through it when held to a 60-W light bulb, the impact was determined a CP. If light was not visible then the impact was deemed a PP. This procedure was continued until the V_{50} was determined in accordance with the U.S. Army Test and Evaluation Command (ATEC) Test Operations Procedure (TOP) 2-2-710 (1993). The values used in the calculation of the V_{50} are highlighted in grey in the tables contained in the appendix.

6. Results

The results given in the tables in the appendix are summarized in tables 2 (SI units) and 3 (SAE units) in this section. V_{50} limits were obtained for all the targets tested. From the test results, the only plate which did not meet the ELI Ti-6Al-4V requirement (MIL-A-46077D) was the

Table 1. Chemical composition of Ti-5A1-5V-5Mo-3Cr.

Aluminum	4,4–5.7
Vanadium	4,0–5.5
Iron	0.30–0.50
Molybdenum	4.0–5.5
Chromium	2.5–3.5
Oxygen	0.18 maximum
Carbon	0.10 maximum
Nitrogen	0.05 maximum
Zirconium	0.30 maximum
Hydrogen	0.015 maximum
Silicon	0.15 maximum
Yttrium	0.005 maximum
Other	0.30 maximum
Titanium	Balance

Table 2. V_{50} ballistic limit results for Ti-5AL-5Mo-5V-3Cr (SI units).

Heat Treatment	**Threat**	**Thickness (mm)**	**Tested V_{50} ($m{\cdot}s^{-1}$)**	**Standard Deviation ($m{\cdot}s^{-1}$)**	**Required V_{50} ($m{\cdot}s^{-1}$)**
STA	0.30 cal. AP M2	13.86	729	7.6	671.2
BASCA	0.30 cal. AP M2	14.02	697.7	4.4	675.7
STA	0.50 cal. FSP	13.86	916.5	14.7	820.5
BASCA	0.50 cal. FSP	13.82	719.9[a]	7.1	811.7

Notes: STA = solution treated and aged; BASCA = beta annealed, slow cooled, and aged.
[a]Did not meet the V_{50} requirement.

Table 3. V_{50} ballistic limit results for Ti-5AL-5Mo-5V-3Cr (SAE units).

Heat Treatment	**Threat**	**Thickness (in)**	**Tested V_{50} ($ft{\cdot}s^{-1}$)**	**Standard Deviation ($ft{\cdot}s^{-1}$)**	**Required V_{50} ($ft{\cdot}s^{-1}$)**
STA	0.30 cal. AP M2	0.546	2393	24.9	2202
BASCA	0.30 cal. AP M2	0.552	2289	14.5	2217
STA	0.50 cal. FSP	0.546	3007	48.3	2692
BASCA	0.50 cal. FSP	0.544	2362[a]	23.4	2663

Notes: STA = solution treated and aged, BASCA = beta annealed, slow cooled and aged.
[a]Did not meet the V_{50} requirement.

BASCA plate against the 0.50-cal. FSP. The difference between the limit velocity and the specification velocity is the V_{50} difference velocity:

$$V_{50}\ \text{Difference} = \text{Test}\ V_{50} - \text{Required}\ V_{50}. \quad (1)$$

The V_{50} difference plots are shown in figures 4–6. The BASCA plates had lower limit velocities than the STA plates regardless of the penetrator. The BASCA plate exhibited marginal improvement in performance over Ti-6Al-4V with a 21.9 $m{\cdot}s^{-1}$ (72 $ft{\cdot}s^{-1}$) or 3.2% increase in the

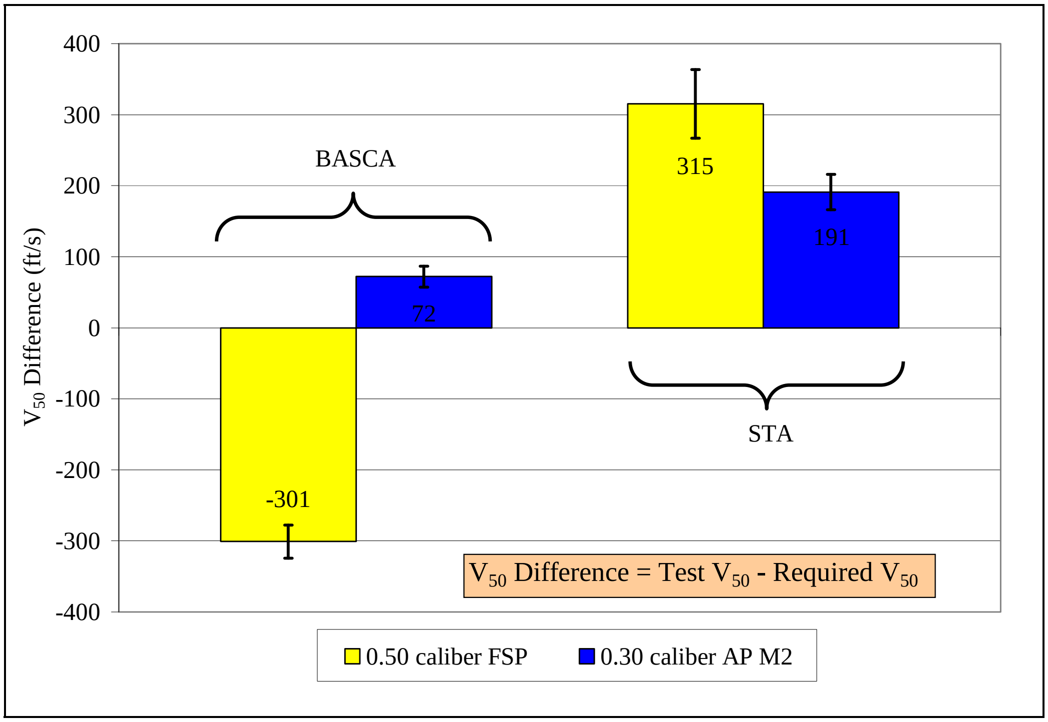

Figure 4. V_{50} difference plot for the Boeing Ti-5Al-5V-5Mo-3Cr high toughness and high strength (STA) 13.9-mm-thick plates subjected to 0.50-cal. FSP and 0.30-cal. AP M2 threats comparing the results vs. the Ti-6Al-4V requirement for equivalent thickness.

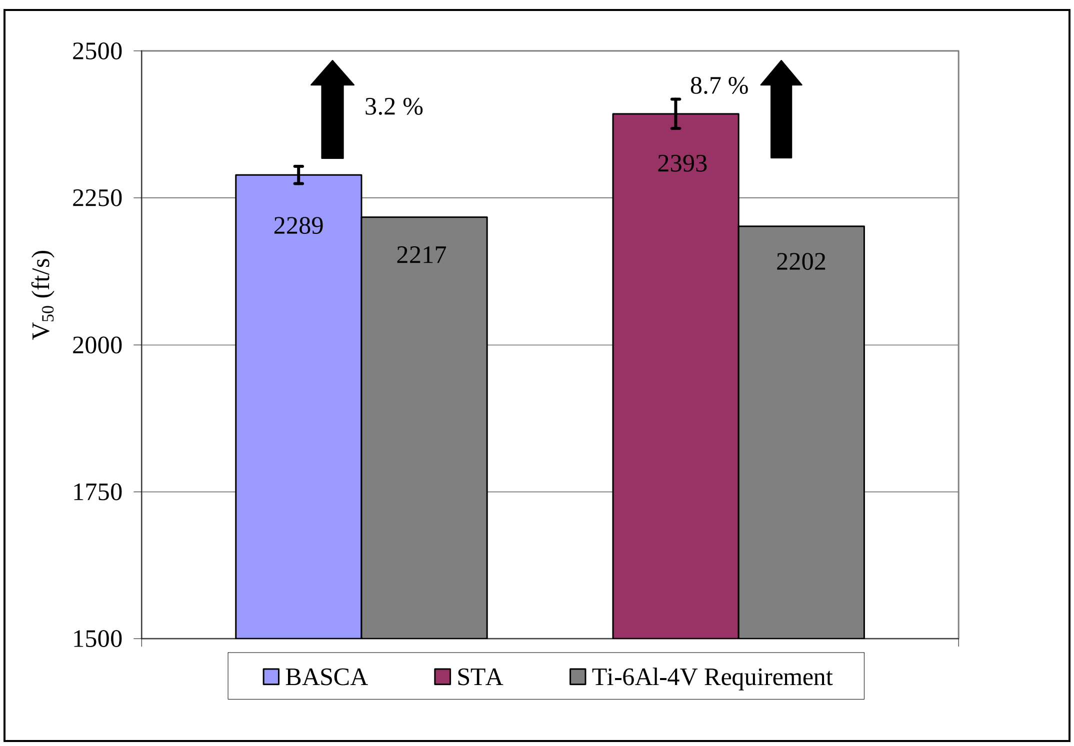

Figure 5. V_{50} results for the Boeing Ti-5Al-5V-5Mo-3Cr high toughness and high strength (STA) 13.9-mm-thick plates subjected to 0.30-cal. AP M2 and the comparison to the Ti-6Al-4V requirement velocities for equivalent thickness.

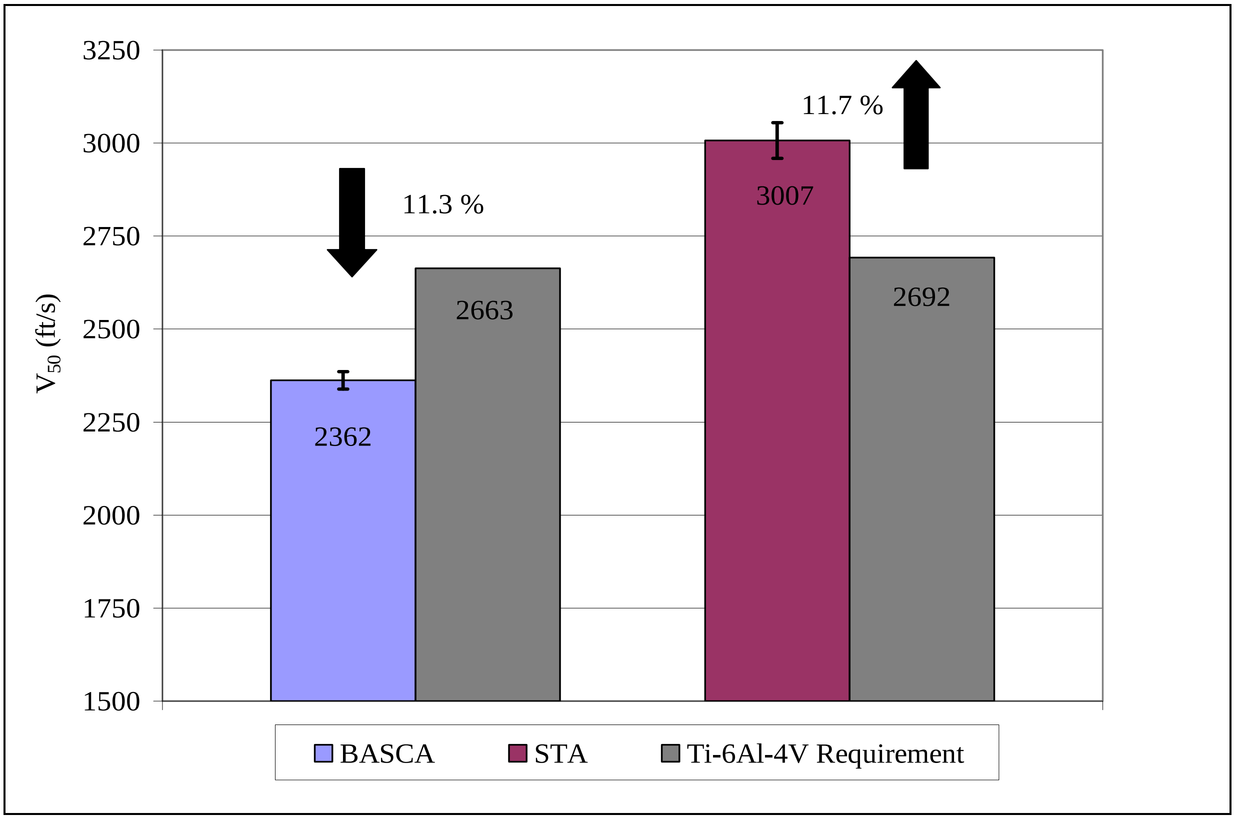

Figure 6. V_{50} results for the Boeing Ti-5Al-5V-5Mo-3Cr high toughness and high strength (STA) 13.9-mm-thick plates subjected to 0.50-cal. FSP and the comparison to the Ti-6Al-4V requirement velocities for equivalent thickness.

V_{50} against the 0.30-cal. AP M2, while the STA plate improved by 58.2 $m \cdot s^{-1}$ (191 $ft \cdot s^{-1}$), an 8.7% increase. The difference in performance for the two heat treatments against the 0.50-cal. FSP was more dramatic. The V_{50} for the BASCA plate dropped 11.3% or 91.7 $m \cdot s^{-1}$ (301 $ft \cdot s^{-1}$) below the required velocity while it increased 11.7%, 96.2 $m \cdot s^{-1}$ (315 $ft \cdot s^{-1}$), over the V_{50} requirement with the STA heat treated plate, as can been seen in figure 6. The strike and distal sides of the impacted specimens are shown in figures 7 and 8 for the BASCA plate and figures 9 and 10 for the STA plate.

Figure 7. Titanium 5553 high toughness plate after V_{50} testing against the 0.50-cal. FSP threat showing the (a) strike face and (b) the distal side.

Figure 8. Titanium 5553 high toughness plate after V_{50} testing against the 0.30-cal. AP M2 threat showing the (a) strike face and (b) the distal side.

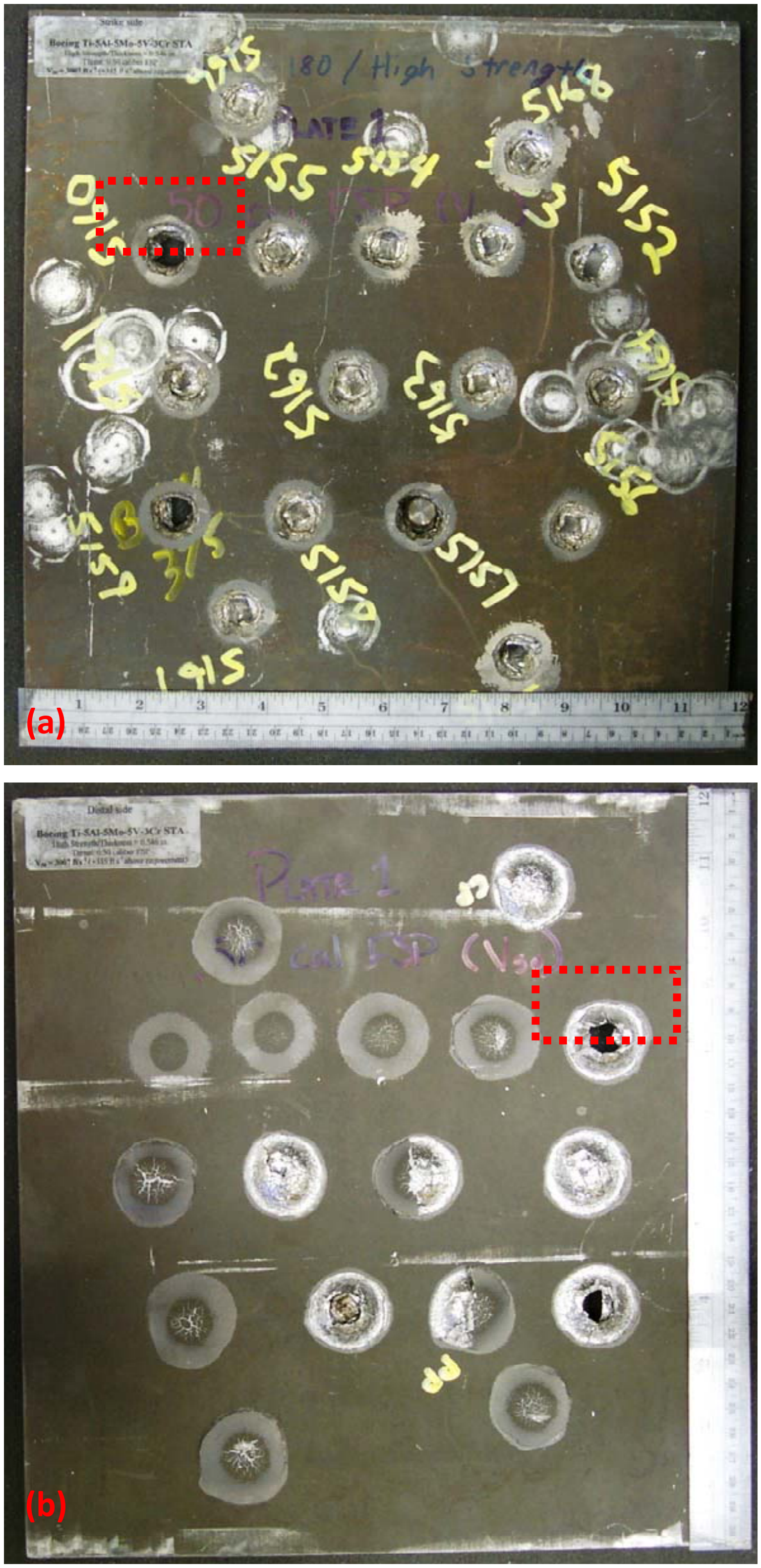

Figure 9. Titanium 5553 high strength plate after V_{50} testing against the 0.50-cal. FSP threat showing the (a) strike face and (b) the distal side. The red box indicates the area sectioned for examination.

Figure 10. Titanium 5553 high strength plate after V_{50} testing against the 0.30-cal. AP M2 threat showing the (a) strike face and (b) the distal side. The red box indicates the area sectioned for examination.

The difference in performance is most likely due to changes in the resulting microstructure from the STA and BASCA heat treatments. Under high strain-rate loading, microstructural effects may increase the propensity for adiabatic shear band formation and growth (Nesterenko et al., 2003). Shear band formation is a low energy failure mode resulting in a decrease in ballistic performance (Meyer et al., 1997; Burkins et al., 1997). The three predominate failure modes typically noted in ballistic impact of titanium are shown in figure 11. The shear localization /plugging and spalling failure modes shown in figure 11a and b are low energy failure modes which adversely affect ballistic performance. The disking failure mode (a form of spalling), figure 11c, is desirable because it incorporates a greater amount of fracture surface without the brittle failure noted in figure 11b.

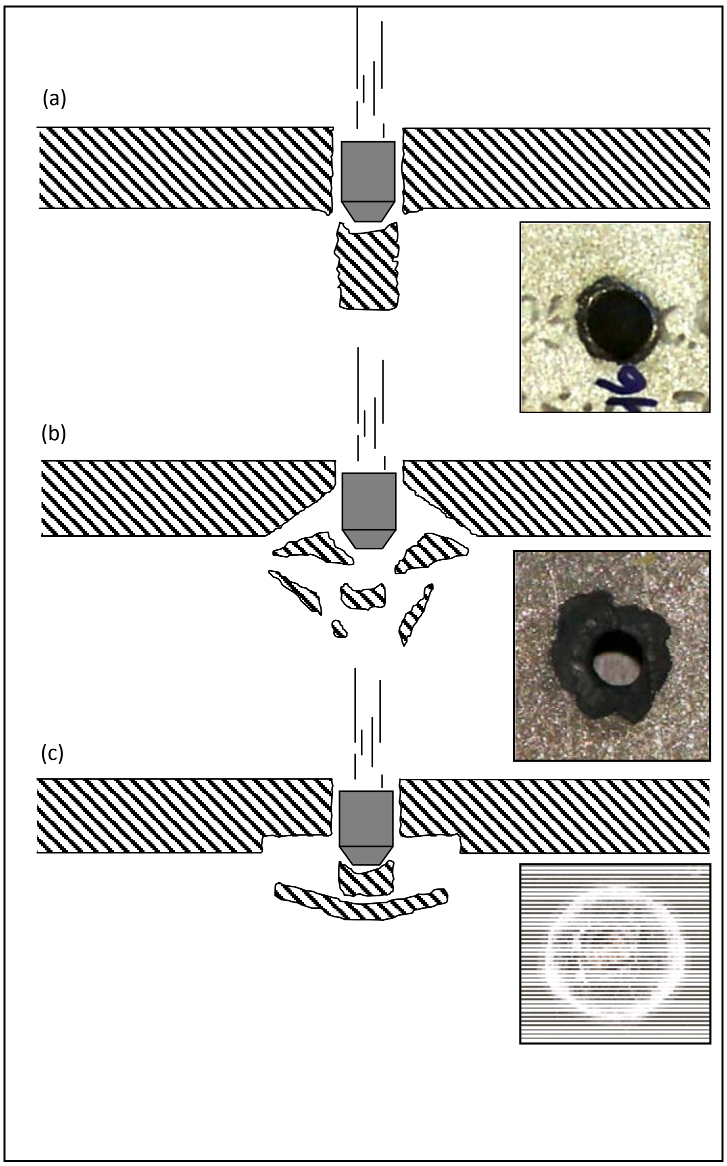

Figure 11. Typical failure modes for titanium armor against FSPs showing (a) shear plugging, (b) spalling, and (c) disking/scabbing.

Spall formation (figure 12b and c) is a common occurrence in high-velocity/hypervelocity impact. Hopkinson was the first to document the phenomenon of spall formation in 1914 (Rinehart, 1975). Spalling results from high-intensity compressive stress wave reflects off a targets free surface as a tensile wave. The tensile wave is never as high in magnitude because the compressive wave, being geometric in shape (e.g., square, triangular, etc.), interacts with the first part of the tensile wave reflecting off the free surface (figure 12). Its magnitude can be determined from the principle of superposition; see figure 12b (Rinehart, 1975).

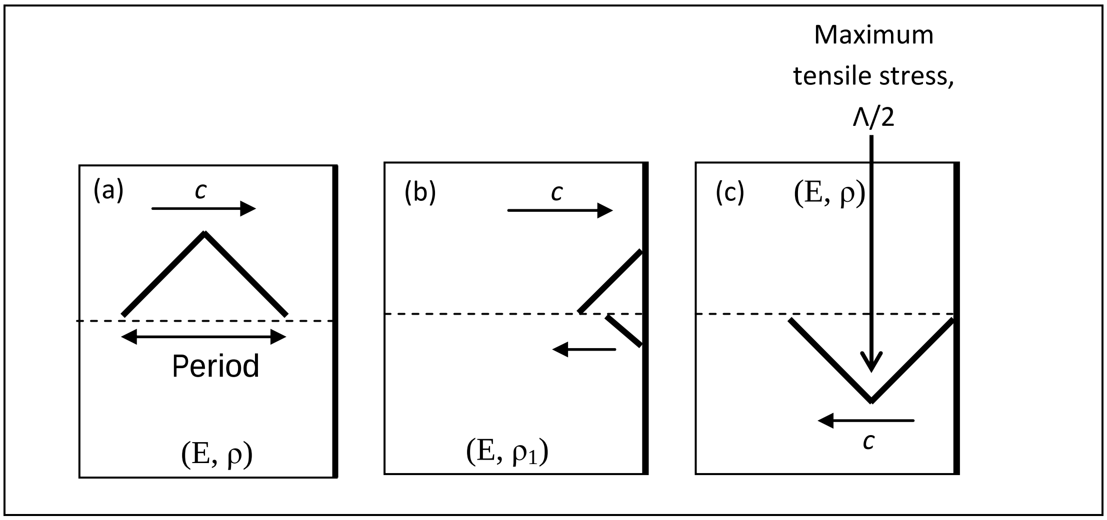

Figure 12. Stress wave propagation showing the (a) incident compressive, (b) wave superposition, and (c) reflected tensile wave. The stress wave speed, c, is given by c = (E/ρ)1/2.

Factors that determine whether spalling occurs include the resistance of the material to fracture, magnitude of the stress wave, and the shape of the stress wave. The shape of the stress wave determines the location in which the superimposed stress wave becomes tensile in nature. This is to say, waves with flat top portions will become tensile further from the free surface because the flat compressive portion will cancel out the tensile wave until they move past one another (Bartus, 2006).

Figure 13b and d shows the cross section of the impact regions of the BASCA and STA plates after a non-perforating impact by a 0.50-cal. FSP. The section locations are indicated with red dashed lines in figures 7 and 9. Against the 0.50-cal. FSP, the BASCA targets failed by shear plugging while delamination and disking were observed in the STA targets. Adiabatic shear bands where noted in the impact region of both heat treatments but were far more pronounced in the BASCA heat treated plates. This is likely to have caused the disking fracture in the STA plates with a volume of approximately three projectile diameters × 4.5 mm deep into the distal side of the plate.

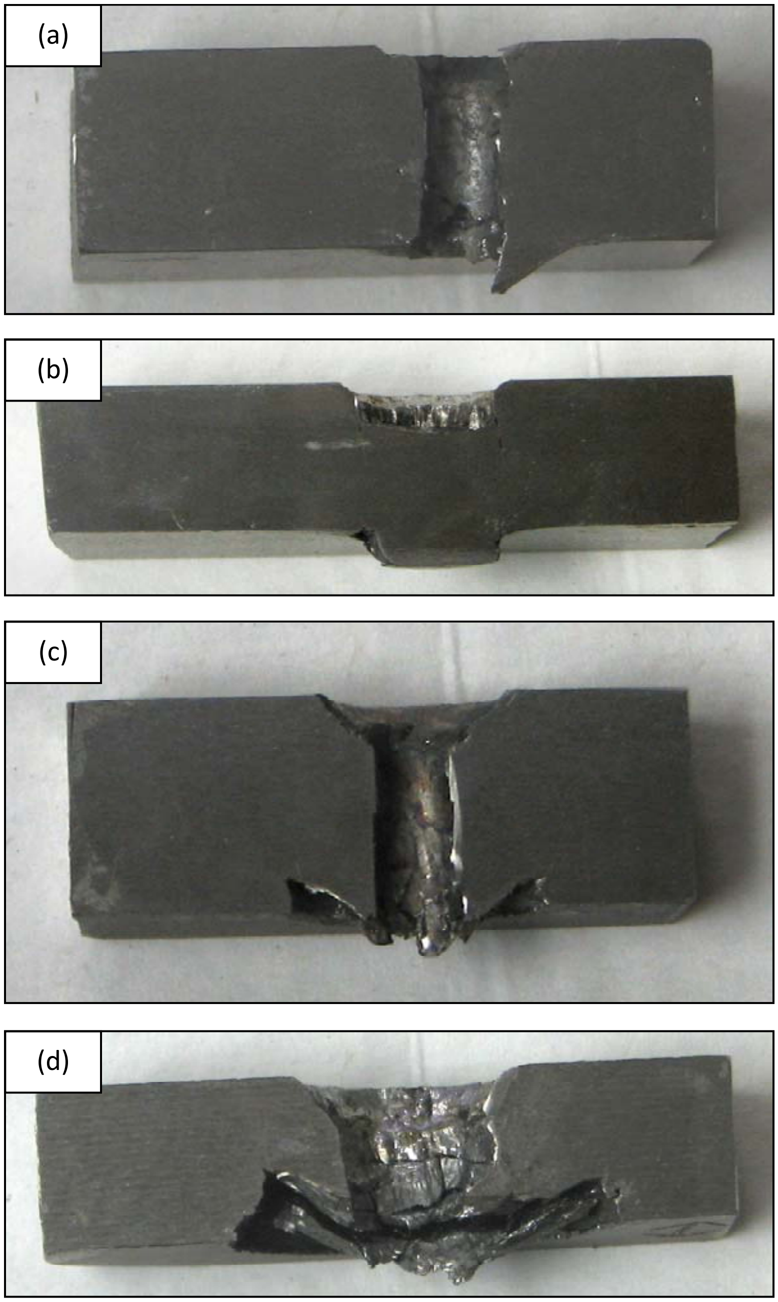

Figure 13. Cross-section views of the BASCA plates impacted by the (a) 0.30-cal. AP M2 and (b) 0.50-cal. FSP and STA plates impacted by the (c) 0.30-cal. AP M2 and (d) 0.50-cal. showing a distinct difference in failure modes.

Similar failure modes were seen in the plates impacted by the 0.30-cal. AP M2 projectiles, figure 13a and c, but were not nearly as pronounced as was the case against 0.50-cal. FSP. One difference was the formation of an impact crater on the strike face, ~1/2 to 3/4 projectile diameters. This resulted from the separation of the copper jacket from the AP core during the penetration process. The penetration process and core separation is shown schematically in figure 14. The copper gilding first begins to mushroom upon contact with the target, figure 14b. As the gilding begins to lose momentum, it forms a crater as it continues to deform and the hard penetrator advances into the target through ductile hole opening and plug formation. The jacket eventually breaks away from the core and ricochets off the strike side of the plate. If the jacket is energetic enough, it may also contribute to hole opening (Me-Bar and Rosenberg, 1997). All tests performed in the present work were close to the ballistic limit and perforation of the plate was by the AP core by itself.

This program demonstrated potential gains in performance for Ti-5553 armor systems over MIL-SPEC Ti-6Al-4V provided a STA heat treatment was used. The potential benefits for U.S. Army applications of the Ti-5553 alloy for armor protection are increased ballistic performance, higher strength, ability to heat treat thick-sections, and near-net shape castability.

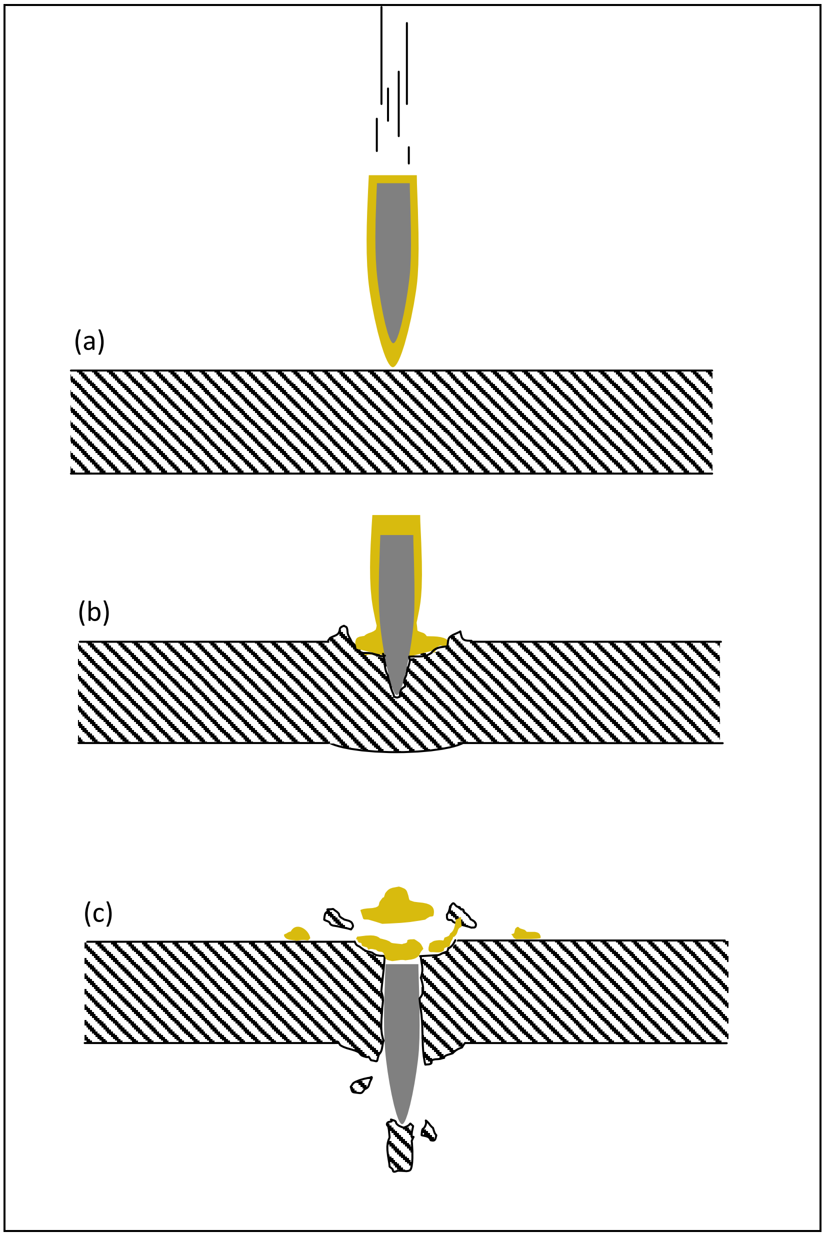

Figure 14. Typical failure modes for titanium armor near the ballistic limit for a 0.30-cal. AP M2 showing (a) the AP core and copper jacket prior to impact, (b) beginning of core penetration into the target and deformation of the gilding, and (c) perforation of the target by the core and ejection of the jacket.

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Appendix. Additional Test Data

This appendix appears in its original form, without editorial change.

Date: 1/24/2007
Target: Boeing Ti-5Al-5Mo-5V-3Cr (high toughness)

Penetrator: 0.50 caliber FSP
Requirement: 2663 $ft \cdot s^{-1}$ (MIL-DTL-46077F)

Shot #	Propellant Wt. (gr.)	Velocity ($ft \cdot s^{-1}$)	Velocity ($m \cdot s^{-1}$)	Result	Projecitle mass (g)
5145	115	2329	709.9	PP	13.4
5146	125	2513	766.0	CP	13.34
5147	120	2384	726.6	PP	13.39
5148	123	2409	734.3	CP	13.41
5149	121.5	2390	728.5	CP	13.43
5150	119	2369	722.1	CP	13.38
5151	116	2367	721.5	CP	13.4

BHN =	387		
Ave thickness =	0.544	in.	
Lowest complete =	2367	$ft \cdot s^{-1}$	
High partial =	2384	$ft \cdot s^{-1}$	
Velocity spread =	55	$ft \cdot s^{-1}$	
ZMR =	17	$ft \cdot s^{-1}$	
V_{50} =	2362	$ft \cdot s^{-1}$	(2 & 2)
=	719.9	$m \cdot s^{-1}$	
Standard deviation =	23.4	$ft \cdot s^{-1}$	
=	7.1	$m \cdot s^{-1}$	
Requirement =	2663	$ft \cdot s^{-1}$	
V_{50} Difference =	-301	$ft \cdot s^{-1}$	

Date:	2/22/2007
Target:	Boeing Ti-5Al-5Mo-5V-3Cr (high toughness)
Penetrator:	0.30 caliber AP M2
Requirement:	2217 $ft \cdot s^{-1}$ (MIL-DTL-46077F)

Shot #	Propellant Wt. (gr.)	Velocity ($ft \cdot s^{-1}$)	Velocity ($m \cdot s^{-1}$)	Result
5280	33.5	2352	716.9	CP
5281	31.5	2210	673.6	PP
5282	32.5	2239	682.4	PP
5283	33	2284	696.2	PP
5284	33.2	2301	701.3	CP
5285	33.1	2309	703.8	CP
5286	32.7	2299	700.7	CP
5287	32.3	2270	691.9	PP

BHN =	387		
Ave thickness =	0.552	in.	
Lowest complete =	2299	$ft \cdot s^{-1}$	
High partial =	2284	$ft \cdot s^{-1}$	
Velocity spread =	31	$ft \cdot s^{-1}$	
ZMR =	0	$ft \cdot s^{-1}$	
V_{50} =	2289	$ft \cdot s^{-1}$	(2 & 2)
=	697.7	$m \cdot s^{-1}$	
Standard deviation =	14.5	$ft \cdot s^{-1}$	
	4.4	$m \cdot s^{-1}$	
Requirement =	2217	$ft \cdot s^{-1}$	
V_{50} Difference =	72	$ft \cdot s^{-1}$	

Date:	1/25/2007
Target:	Boeing Ti-5Al-5Mo-5V-3Cr STA (high strength)
Penetrator:	0.50 caliber FSP
Requirement:	2692 $ft \cdot s^{-1}$ (MIL-DTL-46077F)

Shot #	Propellant Wt. (gr.)	Velocity ($ft \cdot s^{-1}$)	Velocity ($m \cdot s^{-1}$)	Result	Projecitle mass (g)
5152	116	2294	699.2	PP	13.42
5153	121	2388	727.9	PP	13.38
5154	135	2633	802.5	PP	13.41
5155	145	2837	864.7	PP	13.41
5156	150	2842	866.2	PP	13.38
5157	165	3163	964.1	CP	13.39
5158	157	3060	932.7	PP	13.41
5159	161	3095	943.4	CP	13.40
5160	159	3120	951.0	CP	13.42
5161	157	3102	945.5	CP	13.38
5162	154	3016	919.3	CP	13.40
5163	154	3064	933.9	CP	13.41
5164	151	2991	911.7	PP	13.38
5165	152.5	2950	899.2	PP	13.39
5166	153	2962	902.8	CP	13.41
5167	150	2889	880.6	PP	13.39
5168	151	2880	877.8	PP	13.41

BHN =	375		
Ave thickness =	0.546	in.	
Lowest complete =	2962	$ft \cdot s^{-1}$	
High partial =	3060	$ft \cdot s^{-1}$	
Velocity spread =	114	$ft \cdot s^{-1}$	
ZMR =	98	$ft \cdot s^{-1}$	
V_{50} =	3007	$ft \cdot s^{-1}$	(3 & 3)
=	916.5	$m \cdot s^{-1}$	
Standard Deviation =	48.3	$ft \cdot s^{-1}$	
	14.7	$m \cdot s^{-1}$	
Requirement =	2692	$ft \cdot s^{-1}$	
V_{50} Difference =	315	$ft \cdot s^{-1}$	

Date:	2/22/2007
Target:	Boeing Ti-5Al-5Mo-5V-3Cr STA (high strength)
Penetrator:	0.30 caliber AP M2
Requirement:	2202 $ft \cdot s^{-1}$ (MIL-DTL-46077F)

Shot #	Propellant Wt. (gr.)	Velocity ($ft \cdot s^{-1}$)	Velocity ($m \cdot s^{-1}$)	Result
5288	31.4	2215	675.1	PP
5289	32.1	2252	686.4	PP
5290	33.1	2300	701.0	CP
5291	32.6	2267	691.0	PP
5292	33.0	2280	694.9	PP
5293	33.5	2324	708.4	CP

BHN =	364		
Ave thickness =	0.546	in.	
Lowest complete =	2300	$ft \cdot s^{-1}$	
High partial =	2280	$ft \cdot s^{-1}$	
Velocity spread =	57	$ft \cdot s^{-1}$	
ZMR =	0	$ft \cdot s^{-1}$	
V_{50} =	2393	$ft \cdot s^{-1}$	(2 & 2)
=	729.4	$m \cdot s^{-1}$	
Standard Deviation =	24.9	$ft \cdot s^{-1}$	
	7.6	$m \cdot s^{-1}$	
Requirement =	2202	$ft \cdot s^{-1}$	
V_{50} Difference =	191	$ft \cdot s^{-1}$	

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